PRTN 268

The Building-Block Methodology Used for Studying PRNET

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March 30, 1979

I. Introduction

Since the development of the ALOHANET in the late 60's, the concept of packet broadcasting network has received considerable attention as a feasible solution for rapid network deployment, for the use of mobile network elements, and as an economic alternative for point-to-point packet switching. A number of projects have been established to study such networks.

The Packet Radio Network (PRNET) developed under the support of DARPA is an experimental packet switching network facility using a common radio broadcast channel as its transmission medium. Among the objectives of its development are to demonstrate and to characterize the capabilities of packet radio networks. Much effort has been devoted in this regard. A number of studies have been carried out addressing issues concerning various facets of packet radio networks. Such efforts have been proven fruitful in studying specific issues. In this temporary note, we describe a methodology which is used for achieving a systematic characterization of throughput/delay and capacity behavior of the PRNET, as well as for supporting its continuing development.

The variable configuration of a PRNET leads naturally to a building-block approach. Each PRNET deployment may take a different configuration. The possible existence of mobile network elements also allows configuration changes throughout a single deployment.

For analysis using a building-block approach, the PRNET is decomposed into components (building blocks). Characteristics of a building block are studied as functions of its environment. Then, a network or a subnet with any configuration can be analyzed as a compound system consisting of building blocks. For a building-block approach to be effective, it is important that the network decomposition

results in building blocks such that:

i) analysis of a building block is much easier than the analysis of an entire network,

ii) analysis of an integration of building blocks can be efficient, and

iii) interaction (coupling) among the building blocks can be sufficiently considered in their integration so that accurate analysis may be achieved.

Taking a building-block approach may lead to the understanding of not only the behavior of networks of various configurations, but also the impact of a subnet configuration on the network behavior. A building-block model which suits our studies is presented in the next section. In Section III, the building-block methodology used for PRNET studies is described. We discuss, in Section IV, a simple and efficient system-level simulation as an integral part of our methodology.

II. The Building-Block Model

The behavior of a PRNET can be viewed as the aggregative experience of packets traversing the network one hop at a time. Since the effect of packet broadcasting on network behavior is the major concern of our studies, for the model considered the Packet Radio Units (PRUs) and the relations among them form the basic structure of a PRNET.

The one-hop neighbors by radio connection of a PRU, together with the PRU itself, form a subnet. The configuration of this subnet together with the rate of packets for transmission from each of these PRUs form this PRU's one-hop neighborhood. The experience of a packet travelling one hop from a PRU to another can be characterized by the success probability of a transmission and, for CSMA, the time it takes to access the channel. This experience of a packet depends largely upon the one-hop neighborhoods of the receiving and the transmitting PRUs. The influence of the remaining network is reflected in traffic condition of these one-hop neighborhoods. We consider, as the building block of our PRNET model, a PRU and the one-directional hops to its one-hop neighbors. Formally, the building block of our model consists of network functions affecting the progression of a packet between entering the transmit queues of two consecutive PRUs.

The basic building block characterization consists of the success transmission probability and the distribution of channel access time (non-zero for CSMA). They are quantified as functions of the one-hop neighborhoods of the transmitting and receiving PRUs respectively. We categorize a one-hop neighborhood by the following:

1. the number of independent groups* in the one-hop neighborhood, and the number of PRUs in each independent group,

2. the rate of packets for transmission in each PRU.

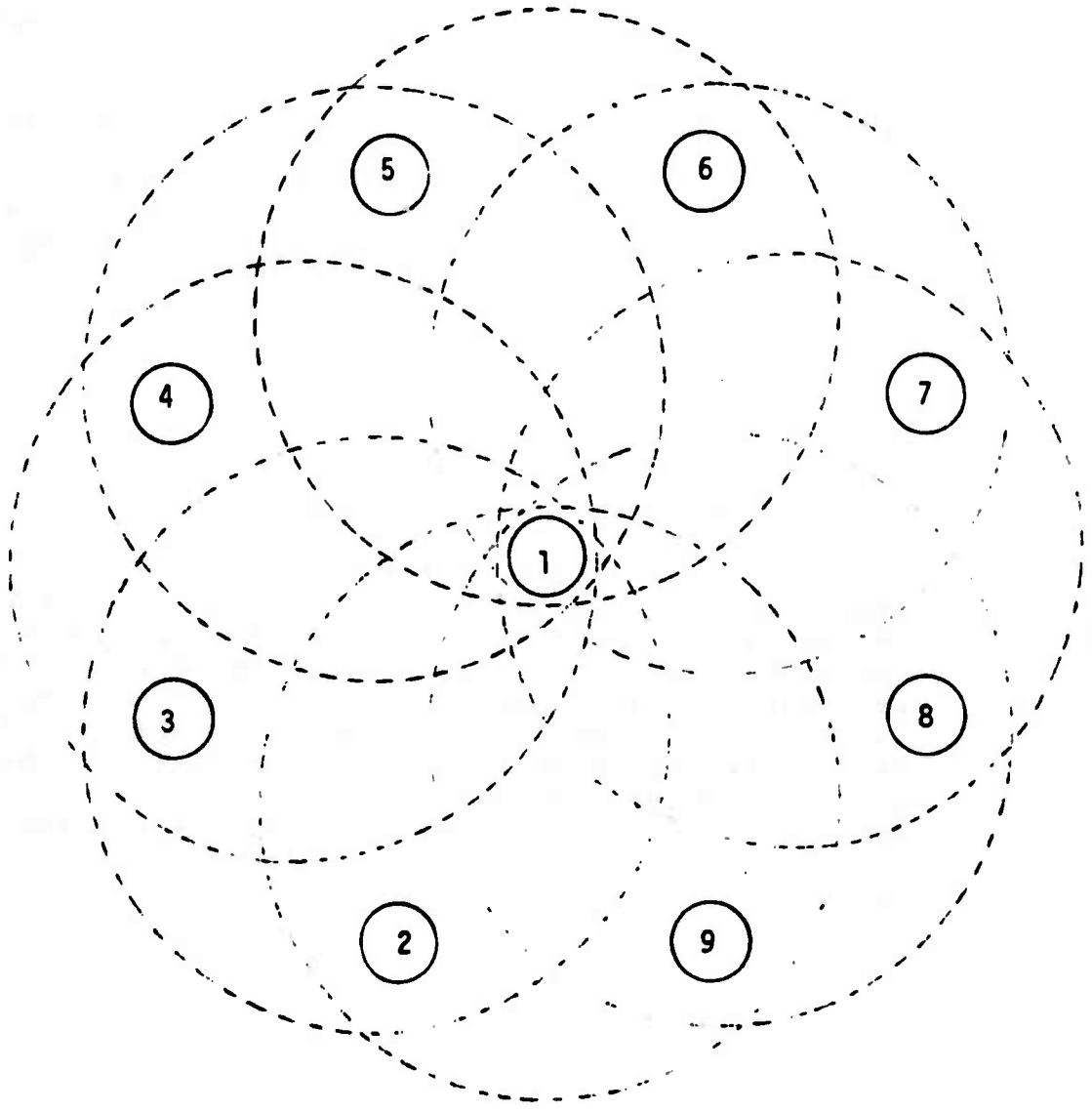
For a realistic configuration, it is reasonable to assume that the number of one-hop neighbors of a PRU is not more than 8 (i.e., the maximum number of mutually hidden PRU is 4 -- see Figure 1).

III. A Methodology for Studying PRNET

The tools available for studying the PRNET include the measurement facilities incorporated in the current PRNET implementation and a detailed simulation of this implementation designed and constructed at UCLA. The advantage of using these tools is their capability of directly studying or closely approximating realistic PRNET behavior. Use of the measurement facilities relies on the availability of the testbed network. It also consumes personnel resource for experiment setup. Both the measurement facilities and the detailed simulation suffer from being relatively inflexible for studying alternative design possibilities or hypothetical conditions, and difficult for studying large scale networks. To compensate, the use of a simple and efficient system-level simulation (Section IV) is incorporated as an integral part of the methodology.

This methodology is based on a building-block approach. Its basic scheme calls for the use of measurement experiments to calibrate the detailed simulation and to verify when necessary the study conclusions. Once calibrated, the detailed simulation can be used for quantifying the building block behavior under various one-hop neighborhoods, and used as a substitute for the testbed network to reduce our

*Two PRUs belong to the same independent group if they have exactly the same one-hop neighboring PRUs within the considered set.



Packet Radio Unit (PRU)

-- the three PRUs within each region (dotted circle) can hear each
-- PRUs 2, 4, 6 and 8 ar mutually hidden from other

Figure 1

dependence on measurement activities. Knowledge of the building block behavior together with the use of system-level simulation form the basis for a flexbile and efficient methodology. This methodology may be employed in PRNET studies for:

i) systematic characterization of current PRNET implementation,

ii) evaluation of design alternatives,

iii) supporting future PRNET developments.

Appendix A details these aspects of PRNET studies and includes a description of the studies currently in progress. In Appendix B, we give an example describing the application of this methodology.

IV. The System-Level Simulation

The system-level simulation is a modulized program with a building-block simulator and a network simulator forming its basic structure.

The building-block simulator simulates the basic PRU functions, e.g., a Poisson process for packet reception, an exponential distribution for packet processing time, and a success probability for its transmission. For features necessary for a specific study, the building-block simuator calls subroutines. Whenever appropriate, this simulator approximates by a constant, a probability or a probability distribution the effect of a system function or the influence of a network condition.

The integration of building blocks is accomplished in the network simulator. The coupling of building blocks is taken into consideration by their mutual influence in terms of probabilistic effects. The network simulator also simulates end-to-end functions (e.g., end-to-end protocol) and network control functions (e.g., routing).

Advantages of such a system-level simulation include the following:

i) The system-level simulation is made efficient by closely simulating only aspects of the PRNET relevant to a specific study.

ii) Due to its simplicity and modulization it is easy to construct, simple to calibrate, and can be readily

modified. Thus, for studying design alternatives, the modification of a network feature may be a matter of replacing a subroutine.

iii) Wherever appropriate we consider the influence of a network condition or the effect of a network function rather than simulate in detail the reality itself. Thus, the system-level simulation may simplify as well as generalize the model it uses. For example, we may substitute the study of a large scale network by the study of its 'critical paths' and the influence of the remaining network on these critical paths. We may simplify the model of a large network to a relatively simple model of its critical paths. As another example, the system-level simulation uses success probability of a transmission together with the time distribution of the interval between transmission attempts for simulating the effect of a channel access mode. It not only eliminates the complexity of simulating the channel access modes, but the resulting model is also generalized and can be used for studying the impact of different channel access modes by simply varying the probabilistic effects.

V. Conclusion

In this note, we have described a methodology employing a building-block approach for studying PRNET. This methodology combines the use of measurement experiments, detailed simulation, and system-level simulation. It takes advantages of each and mutually compensates their weaknesses. It reduces our dependence on the measurement activities. It is also readily adaptable for supporting future development of the PRNET such as the design of multistation and stationless PRNETs. Decomposition of the study of packet radio networks into relatively simple problems offers another advantage of the building-block approach. These simpler problems may yield more readily to mathematical modeling and analysis. Mathematical modeling and analysis may therefore be used in conjunction with this methodology.

Appendix A: PRNET Studies

The objective of the PRNET studies is perceived to be two-fold: to characterize its current implementation and to support its further development. For achieving this objective, we will systematically evaluate the basic capabilities (throughput/delay behavior and network capacity) of the current implementation with respect to various network configurations and varied input traffic. The established methodology and the basic network characterization provide us the capability for supporting the continuing development of PRNET. This end may be achieved by studying the impact of design alternatives. The studies currently in progress include the following:

I. PRNET Characterization

1. Systematic characterization of current PRNET implementation

The objective of this study is to characterize for the current PRNET implementation the impact of various network configurations and input traffic on end-to-end delay, throughput and network capacity. This study will give us not only an evaluation of its basic capabilities, but also a foundation for studies supporting continuing PRNET development. This study requires measurement experiments for calibrating the detailed simulation, the calibrated detailed simulation for quantifying building block behavior, and a system-level simulation program for network characterization. The measurement experiments accomplished to date can be used for calibrating the detailed simulation. Future experiments, expecially those with multi-hop configuration, will help to refine the calibration. Calibration of detailed simulation is progressing in parallel with its further development. The development of the system-level simulation is in progress in conjunction with other studies listed below. Concerted effort using mathematical modeling and analysis is also in progress.

2. Analysis of PRNET involving a Gateway

For interconnecting the PRNET with other networks, a gateway implementing internetworking functions is needed. The impact of the gateway on PRNET network behavior must therefore be assessed. Alternative means for connecting the gateway also need to be evaluated. In the current implementation, whether the gateway resides in the station or it becomes a physically separate device, it is connected to the PRNET through a PRU. From system behavior point of view the gateway can be viewed as an end device. In view of the lack of a physical gateway, its impact is studied by taking it as a terminal with different system parameters. Its study, involving a set of basic PRNET configurations, is currently in progress with priority.

II. Evaluation of Design Alternatives

3. Transmission Order Scheduling

This is a comparative study to evaluate the impact of different PRU transmission order scheduling algorithms on PRNET behavior. This study is in progress using a model consisting of a single PRU and its one-hop neighborhood. The building-block simulator of the system-level simulation is implemented for this study. We study the effect of different scheduling algorithms on the PRU's interaction (transmitting and receiving packets) with its neighbors. The effect is evaluated by the PRU throughput and the one-hop round-trip delay of the PRU traffic as well as the PRU buffer occupancy.

4. Congestion Control Studies

Due to the broadcast nature of the PRNET, congestion control is a significant issue having its impact on various design aspects. No concrete study on this issue is in progress. However, studying the impact of alternate routing is in its planning stage. The impact of LROPs and PDPs on congestion and their effectiveness for maintaining reliability is also in consideration as a potential area for investigation.

Studying design alternatives in other issues, such as flow control, protocol, and channel access mode, is also conceivable. They will be considered once the PRNET characterization is accomplished.

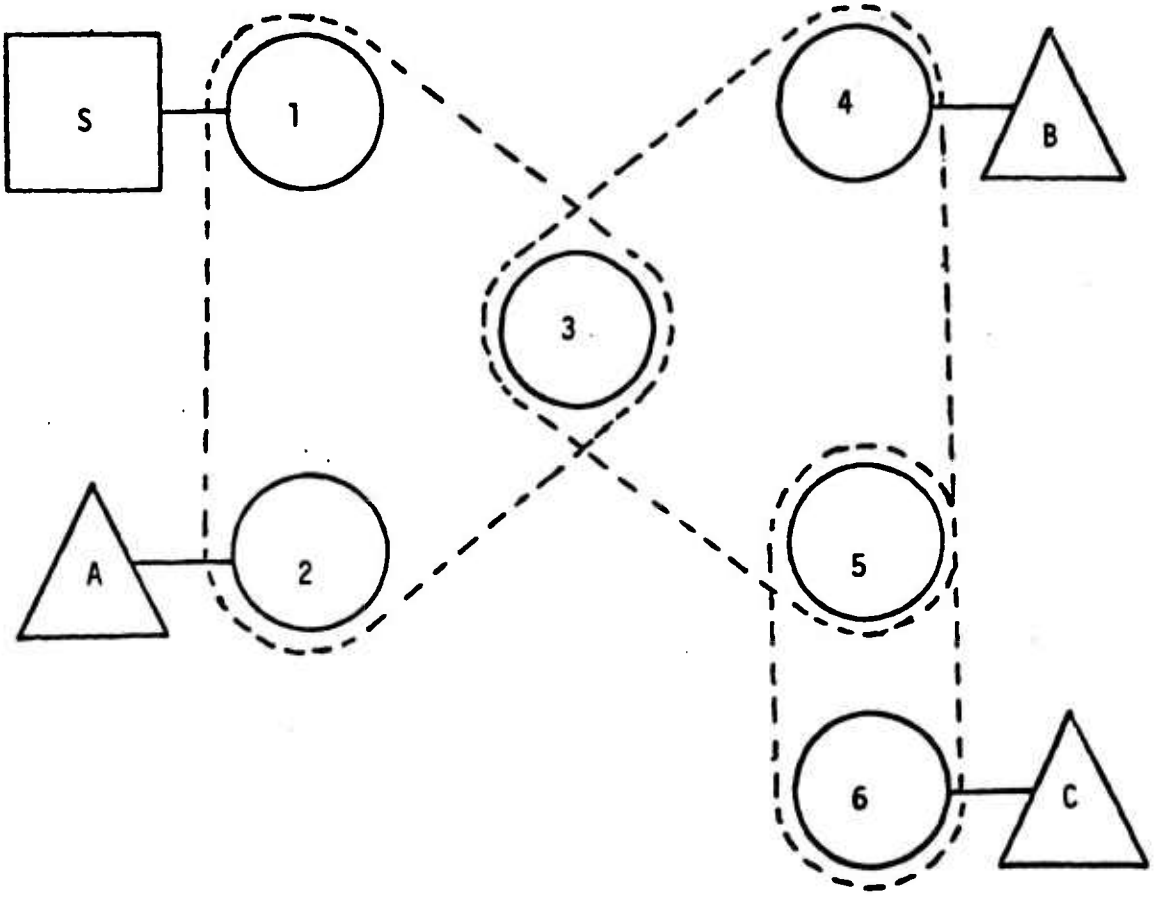
III. Supporting Future Development

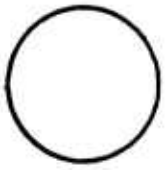
5. Extension of the current model to study design issues for multistation PRNET is under investigation. The immediate objective is to devise a building-block model for studying its routing strategies. Our current building-block model with minor adjustments appears suitable for its throughput/delay studies.

Appendix B: An Example Illustrating the Methodology

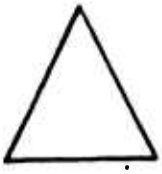
In this example we illustrate the building-block methodology by its application to a study of the end-to-end delay and throughput characteristics betweeen terminals A and B of a network depicted in Figure B1. In this network, we assume PRUs 1, 2 and 3 are in each other's hearing range; so are PRUs 3, 4 and 5, as well as PRUs 5 and 6.

By assuming shortest path without alternate routing, we study in this example the experience of packets travelling the path linking terminals A and B, and PRUs 2, 3 and 4. For wired links we assume a constant delay and a throughput limit. Building blocks for this path consist of PRUs 2, 3 and 4 and the one-dimensional hops to their one-hop neighbors. The one-hop neighborhood of PRU 3, for example, consists of the set of PRUs 1, 2, 3, 4, and 5, and the rate of packets for transmission from these PRUs. Impact of the traffic between terminals B and C on the success probability of a transmission from PRU 2 to PRU 3 is reflected in the rate of packets for transmission from PRUs 4 and 5. Using the building block characterization available to us, a network simulator incorporating end-to-end functions (e.g., end-to-end protocol) would simulate packets travelling this path and yield an evaluation of the end-to-end behavior.

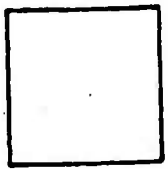




Packet Radio Unit (PRU)



Terminal



Station

Figure B1

Documentation for PRNET System-Level Simulation

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